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Design, Fabrication, Installation, And Operation Of Titanium Seawater Piping Systems

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ABSTRACT

For many years, the U.S. Navy fleet has experienced severe corrosion and erosion problems in copper nickel seawater piping systems. Since titanium is extremely resistant to corrosion and erosion, it has been viewed as a potential solution to these problems. However, certain concerns regarding shipboard use of titanium needed to be addressed: marine fouling, galvanic action with other metals, welding, system fabrication in a normal shipyard environment, testing, and life cycle costs. Over a three year period, Ingalls Shipbuilding division of Litton Industries and the Naval Surface Warfare Center, White Oak, worked with various commercial equipment suppliers to address these concerns. Partially because of the success of this project, it was decided to retrofit titanium systems aboard TARAWA Class LHAs and to specify same for the new LPD 17 Class ships.

INTRODUCTION AND OBJECTIVES

Introduction

Navy shipboard copper nickel seawater piping systems have experienced severe corrosion, erosion, and marine growth blockage. This is evident from review of documented fleet failure data. Titanium has been used for many years on ocean oil drilling platforms and aboard merchant ships and foreign combatants for seawater piping systems and heat exchangers. The reasons for its use include its relatively light weight and extremely good resistance to corrosion and erosion. This history demonstrates that the use of titanium offers a potential solution to the Navy's problems. Titanium is more prone to adhesion of marine growth, and fabrication and installation of titanium piping systems have differentand more stringent requirements than copper nickel systems. Additionally, initial procurement costs are higher for titanium pipe, valves, and fittings. Over a three year period, Ingalls Shipbuilding and the Naval Surface Warfare Center, White Oak, worked with various commercial equipment suppliers to address these concerns. The purpose of the task was to address each of these issues so that the Navy could take advantage of titanium's unique ability to function effectively over the planned 40-year life of today's Navy ships.

Objectives

The objectives of this task were as follows:

1. Determine feasible and cost effective methods for preventing marine growth in shipboard titanium seawater piping systems;

2. Determine the impacts associated with fabrication and shipboard installation of titanium piping systems in a shipyard environment; and

3. Design an actual shipboard titanium seawater piping system and compare the performance and life cycle cost impacts associated with the use of titanium versus copper nickel for this system.

WATER TREATMENT

Overview of Various Fouling Control Methods

Since titanium is more prone to the formation of a surface layer of marine growth than the copper nickel piping systems it might replace, various available water treatment methods were reviewed.

Chlorine. The Navy is familiar with chlorine, having previously used it to purify shipboard potable water systems. In addition, the Navy has conducted extensive study of the use of chlorine for seawater purification. Electrolytic chlorinators are installed on various U.S. Navy piers. U.S. submarines, which have some titanium seawater system components, hook up to the chlorinators to clean out their systems between patrols. Chlorine is a relatively strong halogen that has a harmful effect upon the local marine environment when pumped overboard. Therefore, zero chlorine effluent may soon become required for U.S. waters.

Chlorine Dioxide. This chemical has an advantage over chlorine in treatment of one type of bacteria; but chlorine has the advantage in another area. However, it is still basically chlorine, relatively strong, and harmful to the marine environment. It would also be affected by the zero chlorine effluent requirement if that becomes the law.

Electron Beam Radiation. This method involves subjecting the incoming seawater to nuclear radiation. There are some factories in this country that use this method to purify their drinking water. Because of potential shipboard safety impacts and relative cost, this method was dropped from further consideration.

Bromine. This water treatment method is used throughout the fleet for potable water purification. Being weaker than chlorine, it might not be strong enough to effectively keep seawater piping systems clean. Conversely, although a weaker halogen than chlorine, it is still harmful to the marine environment.

Ultraviolet Light. Ultraviolet (UV) light treatment is used throughout the merchant fleets of the world, including the U.S., to purify potable water. It is allowed by the U.S. Coast Guard and the American Bureau of Shipping as an alternate to bromination. Many American municipalities use UV light treatment, sometimes together with ozonation, to purify drinking water and/or sewage. UV light is environmentally friendly. It is a method not yet used aboard U.S. Navy ships.

Ozone. Bubbling ozone (O_3) into drinking and/or sewage water is a common purification method, and was a probable by-product of the electro capacitance discharge technology experiment discussed in Reference [1]. Ozonation is also environmentally friendly. It is another method not yet used aboard U.S. Navy ships.

Based upon this review, UV light treatment and ozonation were selected for test evaluation and determination of effectiveness for shipboard seawater system purification.

Test System

Titanium Pipe Test Facility. A piping system design was prepared and various vendors agreed to supply components thereof. It was decided to install the proposed test equipment on one leg of a titanium pipe test facility already established in Ft. Lauderdale, Florida. This test facility was built to find solutions for Aegis cooling water system problems.

The original test loop was constructed in 1990. Seawater is pumped directly from the Port Everglades shipping channel, passed through a coarse duplex strainer with 4.76 millimeters (mm) (3/16 inch) hole diameter to filter out large shells and is then pumped at 19.2 liters/second and 8.4 kilograms per square centimeter (kg/cm^2) (300 gpm and 120 pounds per square inch, psi) through the test loop and discharged back into the channel. The loop was originally designed to test a variety of parameters including the effects of different flow rates on biofouling via piping legs of varying diameters incorporated into the titanium test loop to achieve flow velocities of 0.9, 2.4, and greater than 3 meters per second (m/sec) (3, 8, and greater than 10 ft/sec). A blank-off and stagnant leg, with a cruciform piping configuration to allow for observation of undisturbed stagnant seawater, were also part of the original installation. A new test and evaluation plan was drawn up and formalized via a Cooperative Research and Development Agreement (CRADA).

Equipment Supply. Several organizations participated in this new test effort by supplying various equipment. A list of those participants and equipment is contained in Table I.

It was originally planned to fabricate a copper nickel and bronze piping system which would be a mirror image of the already installed titanium piping system. The copper nickel system would be mirror image of the already installed titanium piping system. The copper nickel system would be connected to the titanium system and, with seawater flowing through both, comparative analysis of marine fouling rates could be made and the effectiveness of alternative water treatment methods could be determined. Due to revised priorities, this plan was put on hold. An existing copper nickel system at the shipyard was disassembled and shipped

TABLE I. PROJECT PARTICIPANTS.

ORGANIZATION	EQUIPMENT
ALFA-LAVAL MARINE & POWER	TITANIUM PLATE HEAT EXCHANGER
ASTRO METALLURGICAL	SOME PIPE CUTTING AND FLARING
DOBSON'S USA, INC./AQUAFINE CORP.	ULTRAVIOLET PURIFIER
DRESSER INDUSTRIES	COMPOSITE VALVES
EMERY TRAILIGAZ	OZONE GENERATOR
NAVAL SURFACE WARFARE CENTER CARDEROCK DIV., ANNAPOLIS CORPORATION	TITANIUM SHELL & TUBE HEAT EXCHANGER
OREGON METALLURGICAL CORPORATION	TITANIUM PLATE & PIPE SAMPLES
SPECIALTY PLASTICS, INC.	FIBERGLASS PIPE & FITTINGS
TITANIUM METALS CORP. (TIMET)	TITANIUM PIPE

to the test site as a substitute. It had previously been used for some flowing seawater tests. Although not a mirror image of the titanium system, it was believed that the system would still be useful for comparative analysis.

It was decided to install some fiberglass reinforced plastic (FRP) in the titanium portion of the system to evaluate its performance. Therefore, FRP fittings were retained for all the required elbows, tees, and reducing fittings. Composite valves for all the check, isolation, and sampling valves were included in the system design. Figure 1 depicts the final system design configuration.

It was originally planned to provide titanium flanges with stub ends to weld to the titanium pipe. However, sliding, rotatable flanges would allow more flexibility in system fabrication. Therefore, since the flanges would not see any of the seawater flowing inside the titanium pipe, the use of stainless steel sliding flanges was adopted as the most cost effective alternative.

System Fabrication. Receipt of all the system components at the test site was completed. The coolers and seawater treatment equipment were connected to the supply main via the fiberglass valves and fittings. Since the total connected length of FRP valves and fittings formed a subsystem sufficient for evaluation, no straight sections of FRP pipe were installed. It was therefore decided to utilize the FRP pipe already received for future piping system evaluation at the test site.

The requisite lengths of titanium pipe necessary for completion of the system were determined, cut to the proper lengths, fit with stainless steel sliding flanges, and flared. The finished pipes were connected into the test loops, completing system fabrication. Figures 2 through 7 show the completed installation. Please refer to the Acknowledgments for a complete list of project participants.

System Testing. Successful system lightoff was accomplished on 14 April 1993, with the assistance of representatives from the various equipment suppliers.

Some operational problems were experienced:

1. Backup of water into the ozone generator occurred, but this was resolved by installing a small check valve in the ozone supply tubing.

2. The ambient humidity in the area was so high that the single tower, nonregenerative air dryer became saturated within 24 hours, causing ingestion of excess moisture by the ozone generator. This problem was resolved by replacing the dryer with a two tower regenerative unit.

3. The site was hit by lightning, knocking out both the ozone generator and the UV purifier, in addition to other nonrelated equipment at the facility. The damaged equipment was repaired and put back on line.

4. The system supply pump failed several times and was eventually replaced.

5. Replacement of a nearby navigational aid required that the system be shut down because of the aid's proximity to the system's supply inlet. Operation of the system during installation would have posed a safety hazard to the divers installing the aid and would also have caused an abnormal ingestion of debris into the system.
6. At one point, excessive barnacle encrustation of the system's sea suction basket severely reduced flow performance until the basket was cleaned.

7. Installation of other buildings and support services nearby at the facility caused further disruption and temporary curtailment of operations.

Water Analysis. When the equipment problems were resolved, the water analysis test plan was accomplished as listed below.

1. Ten days running treated, with daily water samples taken for analysis. The UV&O_3 subsystems were both operated at the same time.

2. Open and inspect for marine growth, corrosion, and erosion.

3. Ten days running untreated, with daily water samples taken for analysis.

4. Open and inspect for marine growth, corrosion, and erosion.

5. During both treated and untreated tests, take water samples, let remain stagnant up to ten days, and analyze.

Local personnel at the test site took the water samples, performed the initial analyses required (such as oxygen and ozone content, turbidity, and temperature); packed the samples in dry ice; and shipped them to marine laboratories fo rmore in-depth analysis. Marine and/or micro boilogists conducted the detailed water anslyses showed that UV purification and ozonation significantly reduced colony forming marine organisms in titanium and fiberglass seawater piping systems. Detailed results are contained in the final report, Reference[2].

Open and Inspect Examinations of the Titanium Test Loop. Light biofouling (a matrix of microbial growth and a few macrofouling organisms) and what appeared to be a layer of sand/sediment on the "Y" area was observed during the open and inspect examination. The mineralogical deposits with microbial biofilm could be wiped off easily by hand and the titanium pipe surface showed no discoloration or under-deposit pitting. The titanium plate heat exchanger ws also opened and inspected. No macrofouling was observed after 10 days of untreated seawater running through the titanium plate heat exchanger.

UV and O_3 Lessons Learned. The UV purifier apparatus operated more reliably than the ozone generator, with much less maintenance downtime. Another drawback associated with the operation of the ozone generator involved the requirement for more support services. Both the UV and the ozone units required an electrical power source; however, the ozone unit also required fresh water cooling and a supply of clean, dry air. The manufacturer advised that either compressed oxygen cylinders or an air compressor with dryer would suffice. A compressor and a deliquescent dryer were therefore connected to the air supply

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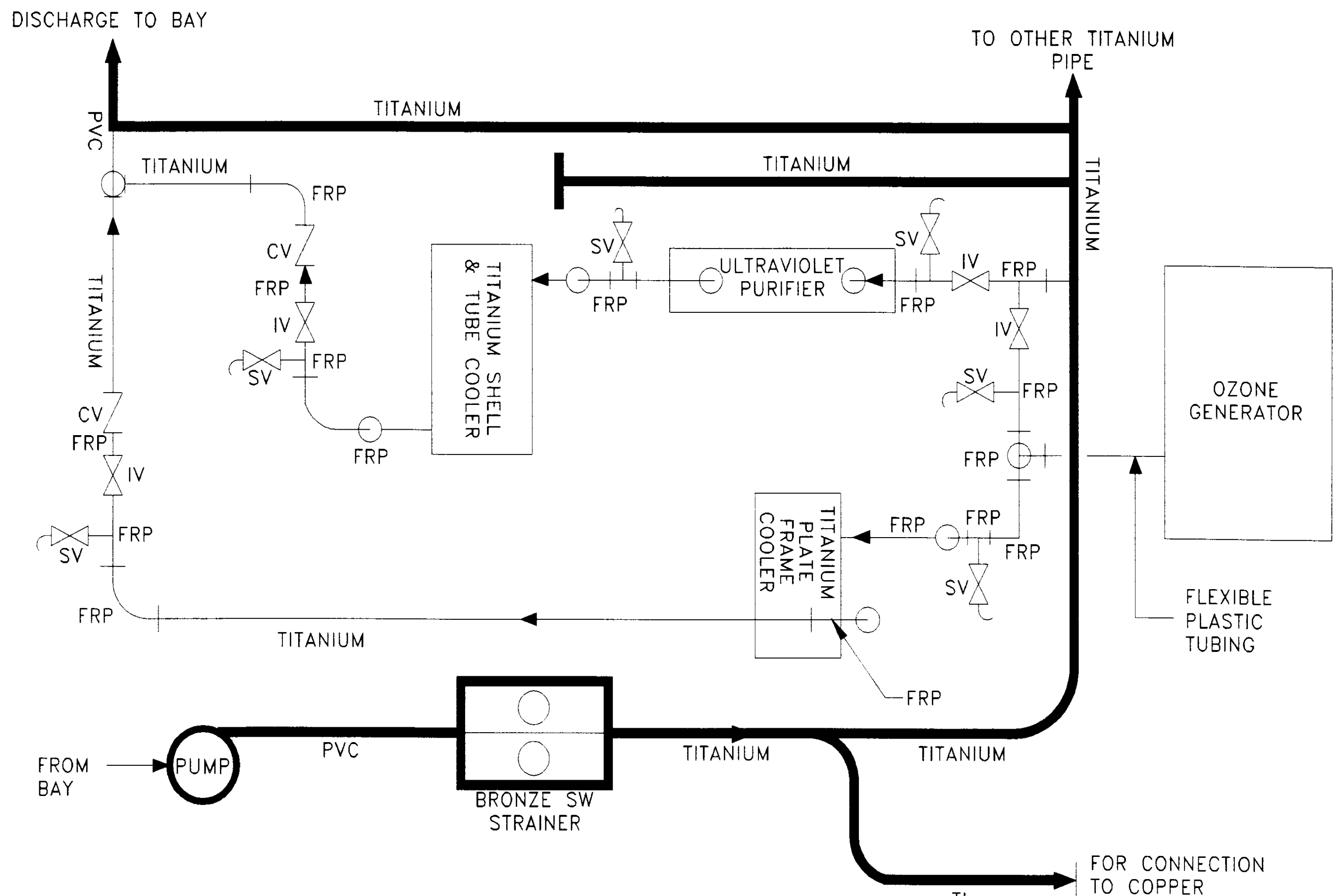
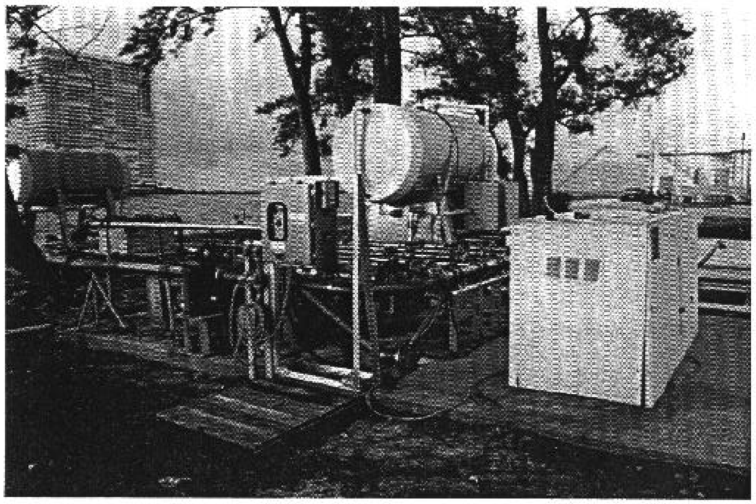


▬	ALREADY EXISTING	IV	ISOLATION VALVE
CV	CHECK VALVE	SV	SAMPLING VALVE
FRP	FIBERGLASS REINFORCED PLASTIC	SW	SEAWATER

Figure 1. Test Equipment Arrangement Sketch

NSWC
Naval Surface Warfare Center
DAHLGREN DIVISION

Figure 2. Ozone generator in white box on right.
UV purifier control panel in center.



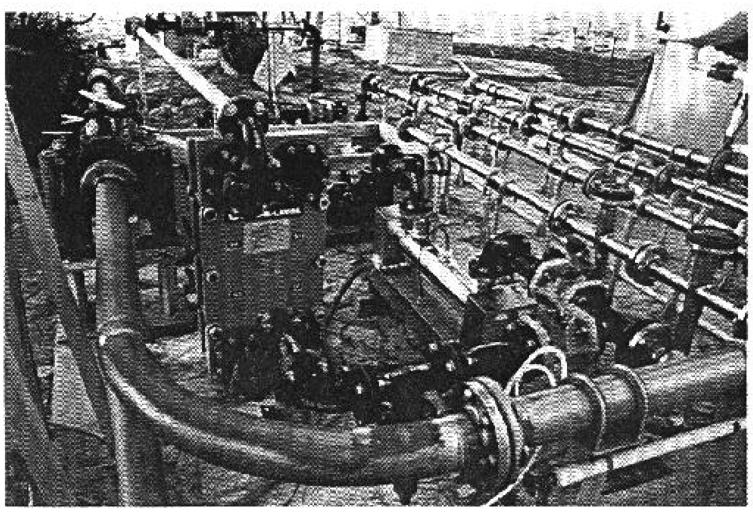


Figure 3. Left to right:
Duplex strainer in SW supply main, Titanium plate & frame cooler, UV purifier.

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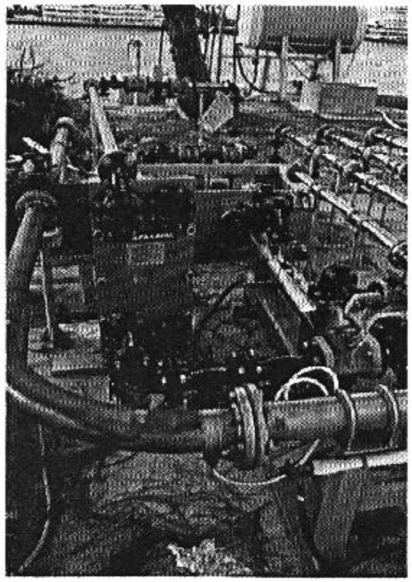


Figure 4. Alfa-Laval titanium plate & frame cooler.

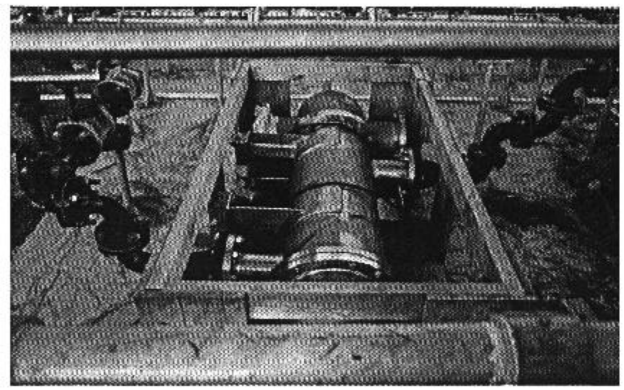
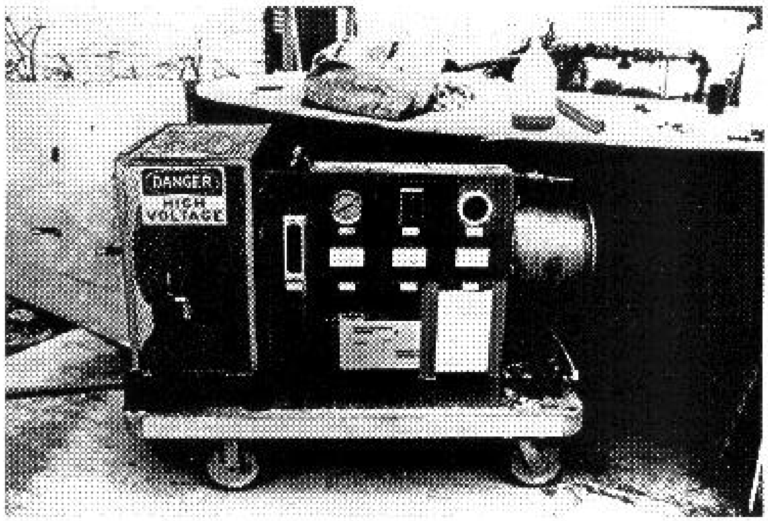


Figure 5. NSWC titanium shell & tube cooler.

Figure 6.   Emery Trailigaz Ozone Generator.



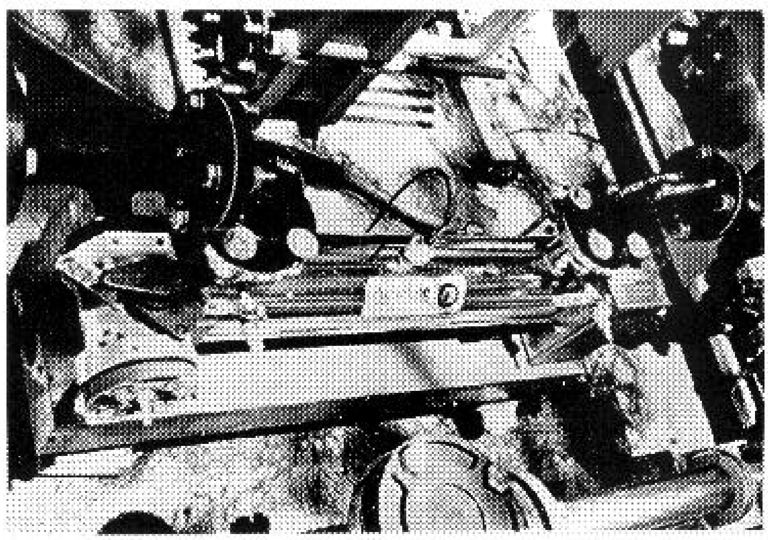


Figure 7. Aquafine Ultraviolet Purifier.

Due to the extremely humid ambient conditions in the area, the deliquescent medium became saturated too frequently, requiring replacement. Therefore, the dryer was replaced with a self regenerative, dual tower desiccant unit. That type of dryer operates by using one tower for drying the air supply, while the second tower is being dried via a small portion of the dry air from the first tower. The functions of the two towers are automatically switched via a timing mechanism.

Ozone generators produce ozone via high voltage (33,000 volts) discharge across glass or synthetic crystal tubes, which have a dielectric constant compatible with the process. UV purifiers kill microorganisms by shining ultraviolet rays across similar glass or crystal tubes through which water is flowing. Either of these apparati would probably be acceptable for pierside use. However, the ozone generator manufacturer requested that the unit be protected from the elements. Therefore, a plywood box was used at the test site to house the apparatus, as shown in Figure 2. The UV apparatus, including the purifier and its control panel, shown in Figures 2 and 3, did not require any special protection from the elements.

For shipboard shock survivability, it is recommended that:

1. The stronger, less brittle synthetic crystal tubes would be preferable to glass.

2. The tubes should be soft mounted, rather than their present land-based hard mounted configuration.

3. This might be accomplished via employment of synthetic rubber mounts at the ends of each tube.

In regards to size and weight, the UV purifier was much lighter in weight and occupied much less space. In regards to shipboard operating personnel safety, the ozone generator produces much higher voltage than the UV purifier. Note the warning label plate on the ozone unit shown in Figure 6.

Because of the superior reliability demonstrated by the UV purifier unit and the other considerations discussed above, at the conclusion of the project testing, the UV purifier was kept on line but the ozone generator was sent back to the manufacturer. Further comparative testing of UV purification is planned at another test facility in King's Bay, Georgia, and the UV equipment manufacturer has agreed to provide a unit for that testing. Chlorination is currently being tested at that facility. However, it is expected that the Environmental Protection Agency (EPA) will soon forbid discharge of any chlorine into U.S. harbors; so UV purification is seen as a promising alternate and environmentally friendly water treatment method.

Composite Components' Performance. The composite valves and fittings tested exhibited no indications of corrosion. No conclusions can be drawn, however, regarding erosion resistance because of the relatively short period of testing.

The composite valves were installed without any exterior protective coating. As a result, the yellow valve surfaces were bleached to a much lighter color within a few months. Discussion with the manufacturer verified that this might be attributed to ultraviolet light from the sun causing an embrittlement of the surface layers of the valve. This could be prevented by application of a protective coating (paint) or by impregnating the composite material with other substances. For instance, the fiberglass tees and elbows installed in the system were impregnated with carbon black to absorb ultraviolet rays. The carbon black distributes the absorbed energy throughout the material. This prevents an excessive rise in the pipe's surface temperature which would cause vaporization of the resin that holds the glass together. Therefore, protective coatings or impregnation would be required for weather deck applications of composite, specifically fiberglass, piping components installed aboard ships.

SHIPYARD FABRICATION

Previous Effort

A Titanium Applications Seminar was held at Ingalls' shipyard in January 1991. The meeting was well attended by representatives of the Titanium Development Association (TDA); Naval Surface Warfare Center (NSWC), White Oak; Naval Ship Weapon Systems Engineering Station (NSWSES), Port Hueneme; Supervisor of Shipbuilding, Conversion and Repair (SUPSHIP), Pascagoula; and various concerned shipyard departments. It was concluded that the shipyard had adequate equipment and personnel to successfully fabricate and install titanium piping systems aboard ships.

Later, one TDA member company provided some titanium plate and pipe samples. The plates were delivered to the shipyard welding laboratory, where they were successfully cut, bent, drilled, and
welded by shipyard personnel.

Commercially Pure Titanium. Bending: A 3.2 mm (1/8 inch) thick piece was bent to a radius of 6.4 mm (1/4 inch) and 19.1 mm (3/4 inch). Both bends were successful with no indication of cracking.

Drilling: A 6.4 mm (1/4 inch) diameter hole was drilled with no difficulty.

Thermal Cutting: A 6.4 mm (1/4 inch) thick piece was cut with both oxy-acetylene and plasma processes. Both processes made acceptable cuts. Because of the speed of cutting, it was difficult to perform manually. The cut edges were heavily oxidized.

Welding: A butt weld was made in an 3.2 mm (1/8 inch) thick plate. Gas tungsten arc welding using Ti-1 wire was utilized. There was no apparent problem with this welding.

Alloy Titanium (6AL-4V). Bending: A 3.2 mm (1/8 inch) plate was bent to a 19.1 mm (3/4 inch) radius with no cracking but with a large amount of springback. A 3.2 mm (1/8 inch) plate was used to attempt to make a 6.4 mm (1/4 inch) radius bend but the material failed brittlely.

Drilling: A 6.4 mm (1/4 inch) diameter hole was drilled with no difficulty.

Thermal Cutting: A 6.4 mm (1/4 inch) plate was cut using oxy-acetylene and plasma processes. As with the CP titanium, both processes will cut the material but the required speeds make manual cutting difficult. Again, the edges were heavily oxidized.

Welding: A butt weld was made in a 3.2 mm (1/8 inch) plate using gas tungsten arc and 6AL-4V wire. A crack developed in the weld. This was attributed to welding over remnant oxides on the cut edges. Because of material availability, a 1.6 mm (1/16 inch) plate was welded and this was successful.

Lessons Learned. Both types of titanium alloys can be processed using shipyard processes. The commercially pure titanium is easier to fabricate and would be the recommended choice for shipboard use.

It was therefore determined that the welding laboratory had all the capability necessary to fabricate grade 2 titanium plates and shapes. This is the "commercially pure" grade installed at the test site and recommended for most shipboard seawater piping systems. Shipboard seawater coolers would require a different grade of titanium alloy, such as the 6AL-4V, which has better heat transfer characteristics.

The 25.4 mm (1 inch) diameter pipe segments were delivered to the shipyard's pipe shop. After bending several segments, pipe shop personnel observed that the thin wall titanium pipe had more springback than the copper nickel or corrosion-resistant (stainless) steel (CRES) they normally dealt with. For instance, using one straight section of titanium pipe, they attempted to form a 127.0 mm (5 inch) radius 90 degree bend. Even though the pipe was initially bent by the bending machine to 114 degrees, when released from restraint, it sprang back to less than 90 degrees. It was determined that the pipe had to be bent to 132 degrees before it would spring back to produce a 90 degree bend with that radius. As long as the springback property was known, the bending machine could be set to compensate for it. This showed that the shipbuilder could perform hot and cold work on titanium plate and pipe in a shipyard environment.

Test Site Supply Main

The test site's 101.6 mm (4 inch) supply main, from the feed pump to the seawater duplex strainer, was composed of polyvinyl chloride (PVC). The test site personnel wanted to change the material to titanium, so that the system would be uniform and to stop leaks. The shipyard volunteered to purchase the materials, fabricate the pipe segment, and ship it to the test site. This would serve the dual purpose of proving that a shipyard has the capability to fabricate titanium piping systems in a shipyard environment and providing the test site with a desired product. Refer to Figure 8 for a drawing of this pipe configuration.

Welding. A proper titanium weld is indicated by the finished weld exhibiting a silver color on the surface. In decreasing order of acceptability, the following chart applies.

Acceptance Criteria

Silver - most acceptable
Light or dark straw (gold) - acceptable
Light blue - marginal
Dark blue - reject
White or gray - completely unacceptable

This is one advantage unique to welding titanium. The very color of the finished weld gives an indication of the quality of the weld. The other normal shipyard materials - such as copper, nickel, bronze, carbon steel, mild steel, stainless steel, HY-80 steel, and aluminum - do not exhibit such easily discernible indications.

It took about two weeks to train a shipyard welder in the proper methods for working with titanium. Some difficulties were experienced with his first attempts at qualification, when he butt welded two pieces of 101.6 mm (4 inch) pipe together. He was welding scrap pieces of the subschedule 5, grade 2 pipe which would be used to fabricate the supply main. The welder's first attempts produced welds with a blue color and some that were powdery white, both being unacceptable. Further welds produced a more acceptable color, but x-rays showed impurities in the weld.

The following corrective actions were taken:

1. Since the faulty welding had taken place in a large open area subjected to stray drafts, a small enclosed booth was fabricated of clear plastic sheets. Welding within this booth prevented relatively cool ambient air from blowing across the hot titanium welds.

2. Because the larger of the two diameters of welding rods had been employed, it took longer for the weld to heat up; but it also took longer to cool down below the 316°C (600°F) threshold temperature required to prevent embrittlement. Therefore, the smaller diameter weld rod was used for subsequent operations.

3. The welding shield at the tip of the rod was enlarged, so that inert gas would be held in place over the hot weld for a longer period of time - until the weld cooled to less than 316°C (600°F).

Taking these measures resulted in a silvery weld surface, which also exhibited no impurities when x-rayed. The welder was therefore qualified and subsequently certified by SUPSHIP, Pascagoula.

Bending. The supply main piping system was to be fabricated from three 4-inch segments which were each 6.1 m (20 feet) long. The finished product would be about 15.2 m (50 feet) long, with an S-bend near one end. To form the S-bend, the pipe was fed into an electrohydraulic bending machine, after insertion of a mandrel with 3 balls, widely spaced. Unfortunately, the pipe formed surface ripples along the inside of the bend. There were ripples for about 25.4 mm (4 inches), followed by about 25.4 mm (4 inches) of smooth pipe surface, followed by about 25.4 mm (4 inches) of ripples, etc. Each ripple was about 3.2 to 6.4 mm (1/8 to 1/4 inchs) deep.

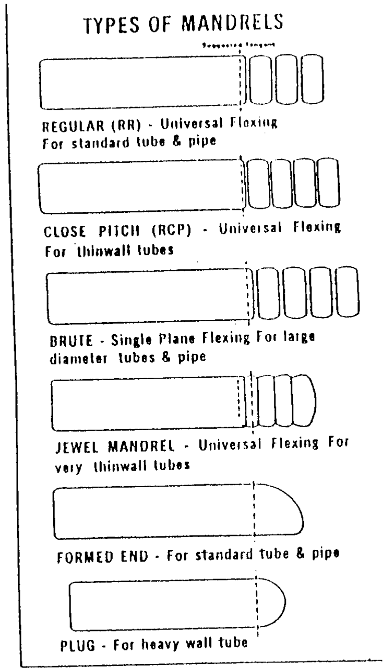
A tool manufacturer recommended that the mandrel be replaced with one having more balls, more closely spaced. This would give more support to the inside surface of the pipe, to help prevent buckling. To support the outside surface, it was recommended that a wiper dye be used. This is a convex surfaced tool that is placed on the machine just before the pipe feeds into the big pulley wheel, prior to bending. See Figures 9 and 10 for more details on mandrels and wiper dyes.

A new section of pipe was put onto the machine; a mandrel having 5 more closely spaced balls was inserted into the pipe; and a wiper dye installed just before the pulley. These measures resulted in a smooth S-bend, with no deformities.

Fabrication. As previously stated, the test facility preferred sliding flanges, in order to allow more flexibility in system alignment. Therefore, titanium flared end fittings were purchased to weld to each end of the five pipe sections. Stainless steel flanges were installed. Galvanic action was not expected because the flanges were on the outside. The qualified welder slipped the flanges onto each section and successfully welded the flared end fittings in place.

Hydro Testing. The finished pipe sections were bolted together and the complete assembly was then hydrostatically tested to 15.7 kg/cm^2 (225 psi) for 30 minutes, twice as long as the normal requirement. The pressure was taken as 1.5 times the maximum seawater system operating pressure aboard TICONDEROGA Class cruisers: the firemain pressure of 10.6 kg/cm^2 (150 psi). No leaks were detected, except for a few drops at one of the gasketed connections. This was probably due to those bolts not being tightened quite enough.

Installation. The main was disassembled and reassembled at the test facility where the system has been operating successfully for three years.



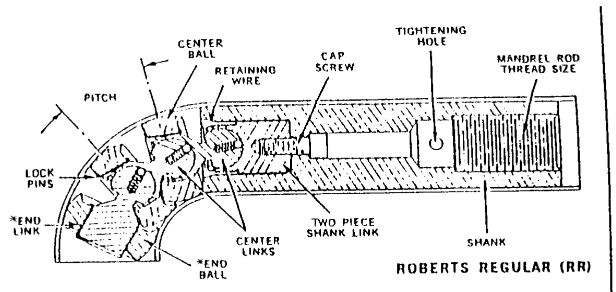


Figure 9. Mandrels

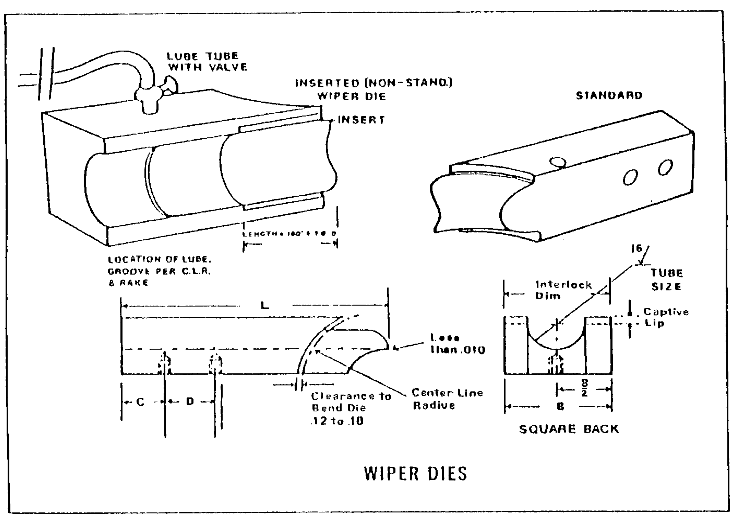


Figure 10. Wiper Dies.

PROTOTYPE SHIPBOARD SYSTEM DESIGN & COST ANALYSIS

Cruiser Design

The Navy AEGIS Program Manager for cruisers and destroyers requested that a prototype aboard an AEGIS cruiser or destroyer. After review of the available failure data for all AEGIS cruisers commissioned since 1983, the forward AEGIS cooling water system, being small and relatively independent, was selected for titanium retrofit. Accordingly, a proposal was prepared and submitted for installing this system aboard CG 73, PORT ROYAL, the last AEGIS cruiser to be built. This proposal was eventually rejected because the cruiser construction program was nearing completion.

Destroyer Design

The next major class of surface combatant under construction was the Aegis destroyer. Review of failure data revealed that the gas turbine generator (GTG) seawater cooling systems were also prone to failure. Since those systems aboard the destroyer are independent, they were selected as design candidates for replacing copper nickel components with titanium.

Piping and flow were redesigned to make optimum use of the advantages inherent in the use of titanium.

The common fix currently employed to remedy leaking 90/10 seawater piping systems involves replacing with 70/30. The 70/30 is a little stronger than 90/10, but is still relatively soft compared with titanium. The shipyard conducted a comparative analysis of pipe acquisition costs: grade 2 titanium versus 90/10 and 70/30 copper nickel. Table II indicates that titanium is about 50 percent more expensive than 90/10 and was equal to or less than 70/30. Titanium once installed should last the projected 40 year life of each ship. As indicated by review of fleet failure data, copper nickel seawater piping system failures are not rare. If copper nickel has to be replaced even once, the titanium pays for itself. Therefore, titanium seawater piping systems would be more life cycle cost effective.

The seawater system design velocity could be increased over the destroyer's currently specified upper limit for copper nickel, 3.6 mps (12 feet per second, fps), because of titanium's superior abrasion resistance. The AEGIS cruiser's seawater systems were designed with a 4.5 mps (15 fps) upper limit. Therefore, the destroyer's allowable velocity was raised from 3.6 to 4.5 mps (12 to 15 fps). The Navy personnel associated with ship noise signatures indicated that the resultant increase in noise generated would be within acceptable limits. One advantage to be gained from increased velocity is decreased proliferation of marine growth on the pipe walls. This may mitigate the necessity for water treatment.

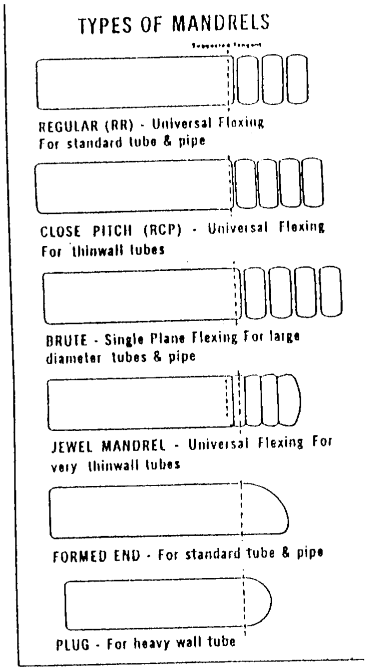
This increase in velocity allowed decreasing the pipe size from 63.5 to 50.8 mm (2-1/2 to 2 inches), making the titanium system more cost effective.

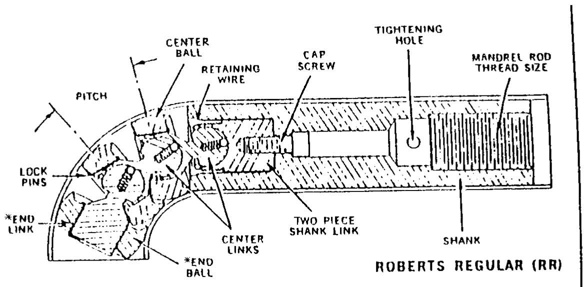
Retention of bronze valves also improved cost effectiveness. Titanium ball valves made in the United States cost about 10 times the price of bronze valves. During a recent trip to Norway, it was determined that titanium valves there were about 3 times more expensive vice 10.

A gas turbine propelled patrol boat, the HIDDENSEE, was built in Russia in 1985 for the East German Navy. When East and West Germany united, the boat was given to the U.S. Navy. Titanium seawater piping systems with bronze valves were part of the design. To prevent galvanic corrosion of the bronze by the titanium pipe, the Russians had inserted composite gaskets, bolt sleeves, and washers at the appropriate interfaces. Examination of the valves determined that, if the valves were those originally installed, they had weathered nine years of operation without deterioration.

Retention of bronze valves would decrease system acquisition cost without seriously degrading long term system operation. Bronze valves last much longer than copper nickel pipe. Composite gaskets were therefore incorporated into the AEGIS destroyer's GTG titanium cooling water system design. This would include any interface with a dissimilar metal: cross connect with the firemain, bronze valves, sea chest, overboard discharge, etc. The Navy will use these gaskets in titanium systems which they plan to install aboard other ship classes, as discussed in the next section.

Again to improve system cost effectiveness, it was decided to retain the bronze and copper nickel system components within the GTG module. The GTG manufacturer was apprised of these intentions, and it was left up to them to decide whether to change their part of the system to titanium. Their subsystem includes three copper nickel and bronze shell and tube


TYPES OF MANDRELS
REGULAR (RR) - Universal Flexing
For standard tube & pipe
CLOSE PITCH (RCP) - Universal Flexing
For thinwall tubes
BRUTE - Single Plane Flexing For large
diameter tubes & pipe
JEWEL MANDREL - Universal Flexing For
very thinwall tubes
FORMED END - For standard tube & pipe
PLUG - For heavy wall tube


TIGHTENING
HOLE
CENTER
BALL
CAP
SCREW
MANDREL ROD
THREAD SIZE
RETAINING
WIRE
PITCH
LOCK
PINS
*END
LINK
TWO PIECE
SHANK LINK
CENTER
LINKS
SHANK
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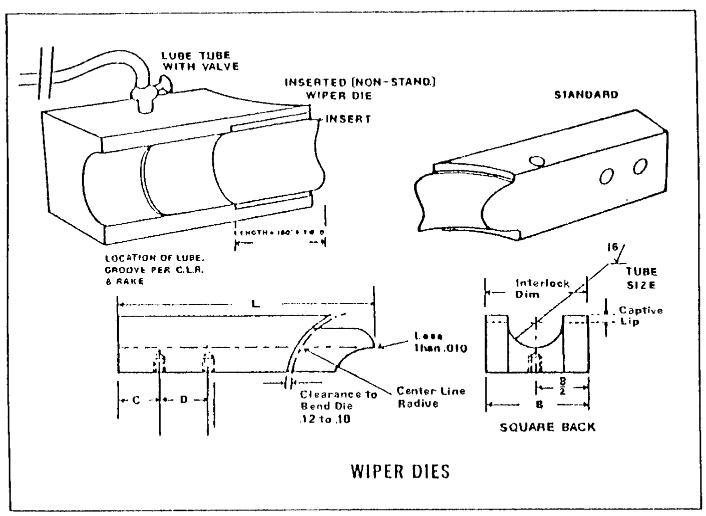
BALL
ROBERTS REGULAR (RR)


LUBE TUBE
WITH VALVE
INSERTED (NON-STAND.)
WIPER DIE
STANDARD
INSERT
LOCATION OF LUBE.
GROOVE PER C.L.R.
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L
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Than .010
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D
Clearance to
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.12 to .10
Center Line
Radius
16
TUBE
SIZE
Interlock
Dim
Captive
Lip
B/2
B
SQUARE BACK
WIPER DIES

type coolers. If they eventually opt for titanium, it is hoped they will change to plate and frame units which are less maintenance intensive (easier to clean and to determine when clean) and are usually smaller and lighter in weight. They are also comparable in cost to the older type of shell and tube coolers.

The piping wall thickness was decreased due to titanium's superior strength. This will decrease system weight and increase ease of installation. Pump characteristics were revised as necessary to accommodate the change in flow. Titanium pumps would be used, if available, for compatibility and decreased weight. If titanium units were not available, composite gaskets would be added.

A rough order of magnitude (ROM) price was estimated for the proposal, based upon material and labor impacts associated with new construction, for a Flight IIA AEGIS destroyer. Although the titanium equipment acquisition costs would exceed that of the copper nickel and bronze equipment originally specified, the ship's life cycle costs would be greatly reduced because the titanium would last longer than the 40 year design life of the ship.

Subsequent Developments

The shipyard met with the Navy and some titanium manufacturers to help determine whether it was practical to retrofit some titanium seawater piping systems aboard the LHA Class during overhaul, and aboard the new LPD 17 Class during construction. It was decided that both plans were practical and cost effective and are now proceeding accordingly. USS SAIPAN, LHA 2, was retrofit with titanium piping systems. Titanium piping systems were also included in the shipbuilding specifications for LPD 17.

Pierside chlorinators are installed at various submarine bases for cleaning seawater systems between patrols. The Seawolf Class submarines have electrolytic chlorinators installed aboard ship. Some submarines currently in service have titanium coolers, but the interconnecting piping systems are Inconel 625, which is more expensive than titanium. Also, Inconel 625 is subject to stress corrosion cracking under these conditions, whereas titanium is not.

Marine organisms in seawater attach themselves to the walls of copper nickel pipe via excretion of an acidic solution. This solution reacts with the metal to create a small pit in which the organisms reside. This also sets up a galvanic couple between the surface beneath the organisms and the still intact protective film on the metal surface just outside the colony. This causes corrosion of the metal surface beneath the colony, deepening the pit. Thus originates the term microbiologically influenced corrosion (MIC). This phenomenon was studied in research projects described in References 3 through 9.

However, since titanium is resistant to almost all acidic attack, marine organisms can only attach themselves to a surface layer of green slime, if one has formed. When water flow through the pipe is started or increased, these organisms are frequently washed away. Therefore, titanium seawater systems will remain cleaner than copper nickel systems, especially at higher allowable flows.

At another meeting, it was stated that rules and regulations would be formulated for titanium fabrication; that any shipyard wishing to fabricate titanium systems or structure for a Navy contract would be visited; and the acceptability of the shipyard's facilities, training, safety, and operational procedures would be determined. It was also decided that, for future ship classes and for retrofit, chlorinators would be installed to prevent marine fouling; and dechlorinators would be installed upstream of overboard discharge fittings to prevent adverse environmental impact.

CONCLUSIONS

Copper nickel seawater piping systems exhibit failures due to erosion and corrosion mechanisms in time frames as small as one year, depending on service.

Cost analysis indicates the following.

1. Titanium pipe prices are about 50 percent greater than 90/10 copper nickel and equal to or less than 70/30 copper nickel.

2. Titanium valves currently cost from 3 to 10 times more than bronze valves.

3. Based upon the copper nickel seawater piping system failure rates reported, utilization of titanium pipe and fittings, with retention of bronze valves, should provide a more cost effective system over the projected 40 year ship life. This assumes a cost effective method to prevent galvanic action between the titanium and nontitanium system components.

Based upon titanium's properties and its use aboard offshore oil rigs in heat exchangers aboard merchant ships, and aboard foreign combatants, it is predicted that titanium seawater piping systems will last the 40 year projected life of U.S. Navy ships.

Use of composite gaskets, bolt sleeves, and washers may be an effective isolation method to prevent galvanic corrosion of nontitanium components of titanium seawater piping systems.

Titanium seawater piping systems can be successfully fabricated in a normal shipyard environment, provided the welding is performed in a draft-free area by a qualified welder.

Ultraviolet radiation and ozone generation are effective, environmentally friendly methods for reducing marine fouling of seawater piping systems. Based upon the equipment tested and the time period involved, ultraviolet radiation equipment appears to be more reliable, safer, lighter weight, smaller, and require fewer support services than ozone generation. Additional evaluation would be warranted, for both water treatment techniques, to determine associated shipboard and/or pierside impacts; these would include both material and labor impacts associated with installation, operation, maintenance, and spare parts inventory. This would determine the long term cost effectiveness of these seawater treatment methods compared with chlorination/dechlorination.

Nonmetallic composite materials installed on ships' weather decks would require a protective coating and/or impregnation to prevent deterioration due to ultraviolet radiation from the sun.

The Navy and private industry do successfully cooperate in testing programs geared to the improvement of ship design, construction, operation, and maintenance.

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